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Does hot weather affect work-related injury? A case-crossover study in Guangzhou, China

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ABSTRACT

Background: Despite increasing concerns about the health effects of climate change, the extent to which workers are affected by hot weather is not well documented. This study aims to investigate the association between high temperatures and work-related injuries using data from a large subtropical city in China.

Methods: We used workers' compensation claims to identify work-related injuries in Guangzhou, China during 2011–2012. To feature the heat effect, the study period was restricted to the warm seasons in Guangzhou (1 May-31 October). We conducted a time-stratified case-crossover study to examine the association between ambient outdoor temperatures, including daily maximum and minimum temperatures, and cases of work-related injury. The relationships were assessed using conditional Poisson regression models.

Results: Overall, a total of 5418 workers' compensation claims were included over the study period. Both maximum and minimum temperatures were significantly associated with work-related injuries, but associations varied by subgroup. One °C increase in maximum temperature was associated with a 1.4% (RR = 1.014, 95%CIs 1.012–1.017) increase in daily injury claims. Significant associations were seen for male and middle-aged workers, workers in small and medium-sized enterprises, and those working in manufacturing sector. And 1 °C increase in minimum temperature was associated with 1.7% (RR = 1.017, 95%CIs 1.012–1.021) increase in daily injury claims. Significant associations were observed for female and middle-aged workers, workers in large-sized enterprises, and those working in transport and construction sectors.

Conclusions: We found a higher risk of work-related injuries due to hot weather in Guangzhou, China. This study provides important epidemiological evidence for policy-makers and industry that may assist in the formulation of occupational safety and climate adaptation strategies.

1. Introduction

Climate change will pose significant health risks to workers in many ways, through increased heat exposure and non-heat related impacts, such as extreme weather events, shifts in disease vectors, industrial transitions and emerging industries (Bennett and McMichael, 2010; IPCC, 2014; Kjellstrom et al., 2016; Schulte et al., 2016; UNDP, 2016). The Intergovernmental Panel on Climate Change (IPCC) stated that there has been an overall increase in the number of warm days and nights at the global scale over the past decades (IPCC, 2014; Pal and Eltahir, 2016). With a predicted increase in ambient temperature due to global warming, heat exposure is presenting a tremendous challenge for occupational health and safety in many countries (Hyatt et al., 2010; Kjellsreom et al., 2013; Roelofs and Wegman, 2014).

Epidemiological studies have shown that workplace heat exposure can increase the risk of occupational injuries and accidents (Kjellstrom

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et al., 2016; Otte im Kampe et al., 2016; Xiang et al., 2014a). Occupational injury is a serious problem affecting the health of workers (Wang et al., 2015). The International Labor Organization (ILO) estimates that worldwide 317 million workplace accidents occur each year, and the economic costs of work-related health problems including injuries are estimated to equal 4–6% of the gross domestic product (GDP) for most countries (WHO, 2014). Recently, there have been growing concerns about the impact of heat stress on occupational health and safety under future climate change scenarios (Kjellstrom et al., 2017; Watts et al., 2017).

Several previous studies have explored the associations between high temperature and work-related injury in Australia (McInnes et al., 2016, 2017; Xiang et al., 2014b,c), Italy (Morabito et al., 2006), Canada (Adam-Poupart et al., 2015; Fortune et al., 2014) and the USA (Garzon-Villalba et al., 2016; Spector et al., 2016). Due to the availability of occupational health and safety data, all surveillance data based studies were from high-income countries. However, the relationship between temperature and work-related injury could vary by industries, gender and age groups in low- and middle-income countries, where socio-economics, demographic characteristics and access to healthcare are much different from high-income countries. In particular, evidence shows that workers in low- and middle-income tropical countries are particularly vulnerable to climate change (Kjellstrom, 2009; Kjellstrom et al., 2009).

The detailed analysis of occupational injury surveillance data can be a useful tool to investigate the effect of extreme weather on workers' health. In this study, we examined the association between high temperature and work injury using data from Guangzhou, a large subtropical city in China. We also aimed to identify which industrial sectors and sociodemographic groups are more vulnerable to hot weather.

2. Method

2.1. Study settings

Guangzhou, with a resident population of 13.5 million and a labor force of 8.11 million in 2015, is the capital city of Guangdong Province. It is the main manufacturing hub of the Pearl River Delta in southern China, and also one of the leading manufacturing regions in the world. With a humid subtropical climate, Guangzhou is characterized by warm winters and hot summers, with plenty of rainfall and sunshine.

2.2. Data sources

Since the Regulations on Work Injury Insurance came into force on January 1, 2004, workers within the territory of the People's Republic of China participate in work-related injury insurance. As the scope of application of work injury insurance was limited, the State Council made significant changes to the Regulations on December 8, 2010 (ILO, 2012). After that, the number of people who participate in work injury insurance scheme has been increasing steadily.

In this study, we obtained workers' injury claim data for Guangzhou for the period of January 1, 2011 to December 31, 2012. The data included demographic and employment information (including age, gender and industry) and information on the occurrence of injuries (the company address at district level and the date on which the injury occurred).

Weather data for Guangzhou including daily maximum and minimum temperatures, and daily average relative humidity, were obtained from Guangzhou Bureau of Meteorology. In this study, we focused on two measures of temperature: daily maximum temperature and daily minimum temperature. Daily maximum temperature was used as a measure of the heat exposure during the day of work. As daily minimum temperatures are typically reached around sunrise, it was used to measure the heat exposure during the sleep time before the day of work.

2.3. Data analysis

A time-stratified case-crossover design was used to estimate the association of heat exposure with work-related injury. The case-crossover study is a modification of the matched case-control study, where each person serves as his or her own control so that known and unknown time-invariant confounders, such as work experience, are inherently adjusted for by study design. In this study, temperature exposure for each case on the date of injury (case day) was compared to exposures when injury did not occur. Confining the control days to the month of injury reduces the influence of long-term time trends (e.g., industry power consumption). Control days were also limited to the same day of the week as for the case to adjust for day of the week. Consequently, there could be a maximum of 4 controls and a minimum of 3 controls before or after the case.

Due to our particular interest in heat effect, the study period was restricted to the warm seasons for Guangzhou (1 May-31 October). Using the time-stratified approach to referent day selection previously described, 731 case days were matched with a total of 2488 referent days. In this way, each case day was matched with up to 4 referent days: 59.6% of cases were matched with 3 referent days and 40.4% were matched with 4 referent days.

We used conditional Poisson regression models (Armstrong et al., 2014), which can allow for over-dispersion and autocorrelation, to analyze the association between temperature and injury risk. Daily maximum temperature and daily minimum temperature were put into separate regression models. Average humidity was included as a time-varying confounder in the models. Considering that previous studies reported non-linear heat-injury relationship, we initially assessed the relationship between temperature and injury risk for non-linearity by including a natural cubic spline with 3 df (Barnett et al., 2017). If the model did not indicate a non-linear relationship, we subsequently estimated the relationship between linear temperature increase and risk of injury.

Additional analyses were performed on stratified data. We conducted separate models for each temperature metric by gender (male and female), age group ($\leq$24, 25–34, 35–44, 45–54 and $\geq$55) and occupational characteristics (business size). We also stratified our analyses by industrial sectors with mostly indoor or outdoor activities, as classified according to expert judgement.

Results for the conditional Poisson models are expressed as relative risks (RRs) with 95% confidence intervals (CIs), and interpreted as percentage change in daily injury claims per ˚C increase in temperature. Effects were considered statistically significant if the p value < 0.05. All analyses were conducted using R (version 3.4.0; R Foundation for Statistical Computing, Vienna, Austria).

2.4. Ethical approval

This study was approved by the medical ethics committee of School of Public Health, Sun Yat-sen University. Data used in the study were unidentifiable and individual patient consent was not required.

3. Results

Overall, a total of 9550 workers' compensation claims were identified in Guangzhou between 2011 and 2012, and 5418 work-related injuries were included for analysis over the period of warm seasons. As shown in Table 1, the majority of claimants were male (77.2%) and aged 25–44 years (63.0%). About half (53.6%) of all injury claims occurred in the small enterprises. The percentage of injury claims for workers in manufacturing was 47%.

The daily average minimum and maximum temperatures during the study period were 24 ˚C and 32 ˚C, respectively. Fig. 1 demonstrates the distribution of daily injury claims and outdoor temperatures for Guangzhou.

Table 1
Numbers of workers' injury claims in Guangzhou, China between 2011 and 2012.

Classification	Warm seasons	All seasons
Total	5418	9550
Gender		
Male	4207	7377
Female	1211	2173
Age group		
≤24	900	1541
25–34	1553	2753
35–44	1892	3327
45–54	932	1691
≥55	141	238
Business size[a]		
Small	2916	5119
Medium	1643	2908
Large	859	1523
Industrial sectors[b]		
Manufacturing	2555	4485
Finance, property and business services	1527	2683
Wholesale and retail trade	566	1021
Transport, storage and post	72	128
Construction	67	96
Others	631	1137

[a] The industry sector was categorized according to Classification of National Economic Sectors (GB/T 4754-2011).

[b] The business size was categorized according to Notice on Issuing the Provisions on the Classification Standard for Small and Medium-sized Enterprises (No. 300 [2011] of the Ministry of Industry and Information Technology, China).

Fig. 2 shows the relative risks of work-related injury for temperature increase. One ˚C increase in maximum temperature was associated with a 1.4% (RR = 1.014, 95%CIs 1.012-1.017) increase in daily injury claims. Significant associations were seen for male and middle-aged workers, workers in small and medium-sized enterprises, and those working in manufacturing sector. And 1 ˚C increase in minimum temperature was associated with 1.7% (RR = 1.017, 95%CIs 1.012-1.021) increase in daily injury claims.

Table 2 presents the associations between ambient temperature and work-related injury for all cases combined, demographic subgroups and occupational characteristic subgroups. Either maximum or minimum temperature was significantly associated with work-related injuries, but the associations varied in different subgroups. As shown in Fig. 2, estimates presented are those of conditional Poisson regression models assuming linear temperature-injury relationships.

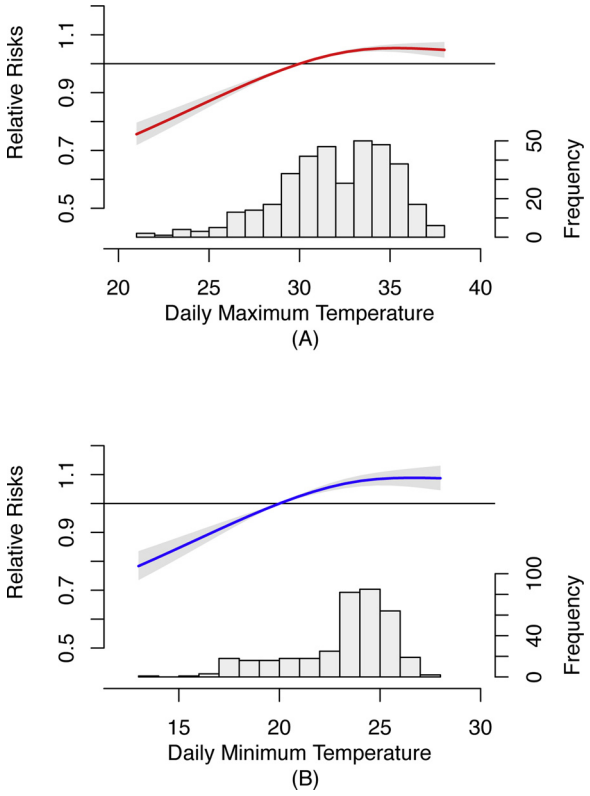

Fig. 2. Associations[a] between daily maximum temperature and work-related injury risk (A), and minimum temperature and injury risk (B) with temperature distributions. The inserted histogram showed the frequency distribution of daily temperature. [a]Relative risk of injury for daily maximum temperature and minimum temperature, compared to the reference 30 ˚C and 20 ˚C, respectively, were estimated in the non-linear model with a natural cubic spline.

As in Table 2, for daily maximum temperature, daily claims increased by 1.4% for both male and female workers per ˚C increase. Among all age groups, workers aged 25–34, 35–44 and 45–54 were significantly associated with maximum temperature, by 1.8%, 2.1% and 0.9% in injury claims per ˚C increase in maximum temperature. In contrast, no significant associations for workers aged < 25 and ≥55 were observed.

Significant associations of daily maximum temperature with work

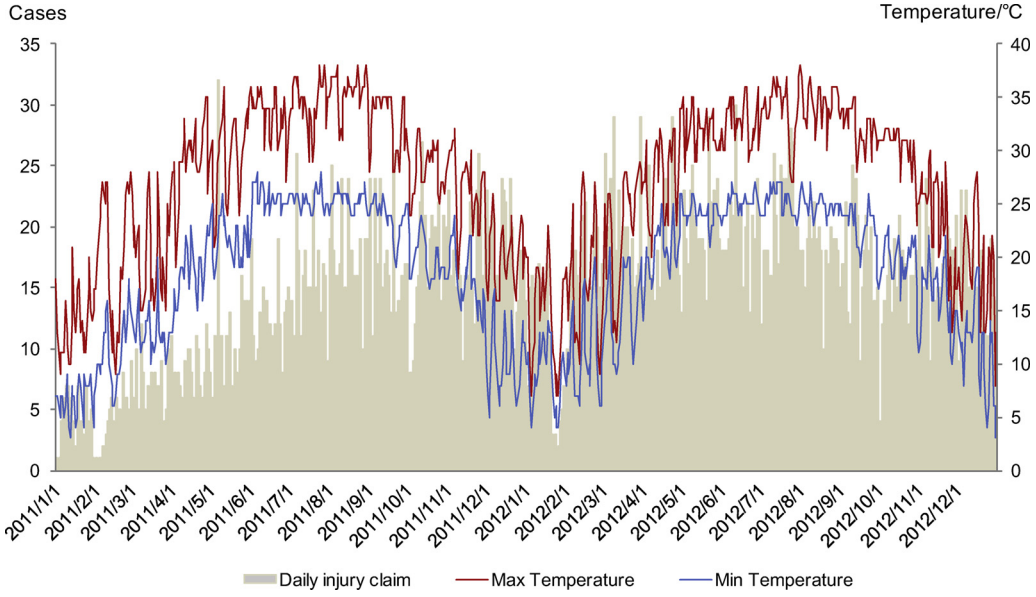

Fig. 1. The distribution of daily injury claims and daily maximum and minimum temperatures in Guangzhou, China between 2011 and 2012. The grey column represents daily injury claims. The red and blue line represent daily maximum and minimum temperature, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Relative risks (RR) of work-related injury for per °C increase in daily temperature, Guangzhou, 2011–2012.

	Daily Max. Temperature		Daily Min. Temperature	
	RR	95% CIs	RR	95% CIs
Total	**1.014**	1.012–1.017	**1.017**	1.012–1.021
Gender				
Male	**1.014**	1.011–1.016	**1.013**	1.009–1.018
Female	**1.015**	1.008–1.021	**1.030**	1.015–1.045
Age group				
< 25	1.005	0.998–1.012	1.008	0.992–1.025
25–34	**1.018**	1.013–1.024	**1.027**	1.016–1.038
35–44	**1.021**	1.017–1.024	**1.012**	1.004–1.021
45–54	**1.009**	1.001–1.016	1.009	0.992–1.026
≥55	0.989	–	0.958	0.915–1.002
Business size				
Small	**1.014**	1.011–1.017	1.004	0.998–1.010
Medium	**1.017**	1.013–1.022	1.009	0.998–1.019
Large	1.003	0.995–1.011	**1.049**	1.029–1.068
Industrial sectors				
Sectors with mostly outdoor activities				
Transport, storage and post	1.008	0.987–1.029	**1.411**	1.335–1.493
Construction	1.001	0.979–1.024	**1.500**	1.426–1.580
Sectors with mostly indoor activities				
Manufacturing	**1.019**	1.015–1.022	1.002	0.994–1.010
Finance, property and business services	**1.014**	1.009–1.019	1.009	0.998–1.020
Wholesale and retail trade	1.008	0.996–1.020	1.094	1.065–1.125

Bold represents significant *p*-values.

injury were also observed in small and medium-sized enterprises, with daily claims increased by 1.4% and 1.7%, respectively, for each 1 °C increase in maximum temperature. In contrast, no significant association for large enterprises was found. Industry-specific analysis showed that there was a significant increase in injury claims with an increase in maximum temperature for 'manufacturing' (1.9%) and 'finance, property and business services' (1.4%).

For daily minimum temperature, associations of the temperature with work injury were also significant. Male and female workers, middle-aged workers (25–34 and 35–44 years), workers in large-sized enterprises were vulnerable to the minimum temperature. An interesting finding was significant associations among those working in outdoor industries such as 'transport, storage and post' and 'construction'.

4. Discussion

We found a positive relationship between high temperature and work-related injury in Guangzhou, China. Both maximum and minimum temperatures were significantly associated with injury risk, but association sizes varied by worker group. To the best of our knowledge, this is the first study quantifying the impact of outdoor temperatures on work-related injuries in China.

In our study, per 1 °C increase in maximum temperature was associated with a 1.4% increase in daily injury claims. This finding is consistent with those reported by previous studies (Adam-Poupart et al., 2015; Xiang et al., 2014c). Xiang et al. (2014c) found a 1 °C increase in maximum temperature was associated with a 0.2% increase in daily injury claims in Adelaide, Australia, while Adam-Poupart et al. (2015) modeled work-related injury compensations and outdoor temperature revealing a 0.2% increase with each increase of 1 °C in Quebec, Canada. The smaller association sizes in these studies could be explained by their temperate or cold climates.

Less clear is the mechanism by which maximum temperature exposure could be related to work injury. Physical and behavioral factors such as slippery sweaty hands, foggy glasses, hot tools and working faster to avoid the heat may have acute impacts on injury risk (Adam-Poupart et al., 2015; Pilcher et al., 2002), but it could also be speculated that more sustained effects of heat are related to a combination of these physical issues with other factors such as fatigue and dizziness (Pilcher et al., 2002). Future epidemiological research should continue to narrow the focus around cause-specific work injury to highlight potential important mechanisms.

We also found the significant positive associations between injury risk and daily minimum temperature. Such findings regarding the risk of occupational injury and minimum temperature are relatively new. Daily minimum temperature actually measures the minimum overnight temperature prior to day of injury, which may reflect the influence of the sleeping thermal environment at night. There is accumulating evidence that sleep problems elevate the risk of injury in the workplace (Salminen et al., 2010; Uehli et al., 2013, 2014). Sleep is essential for the body to recover from both physical and psychological fatigue suffered through the day and restore energy to maintain bodily functions. And thermal environment could be one of the most important factors that affect human sleep (Lan et al., 2014).

Maximum and minimum temperatures could be mutually confounded by daily weather. We examined this by a model in which maximum and minimum temperatures were co-adjusted. The estimates of minimum temperature did not change significantly if maximum temperature was used as a confounding variable, but the results for maximum temperature do change. To avoid multicollinearity, however, we fitted maximum and minimum temperatures in separate regression models.

Our study suggests that both thermal comfort in workplaces as well as the sleeping environment may be important for occupational health. Although we could not find published data on this subject, it is possible that the effect of hot weather on occupational health and safety will be mediated through not only occupational heat stress at daytime but also sleeping thermal environment at night. In most regions, the frequency of warm days and nights will increase in the next decades (IPCC, 2014). Therefore, climate change is presenting and will continue to present occupational safety and health hazards to workers (Luo et al., 2014; Sahu et al., 2013; Sett and Sahu, 2014). However, workers have received inadequate attention in the analysis of impacts of climate change (Roelofs and Wegman, 2014). Additional surveillance, research and risk assessment are needed to better characterize and understand how occupational safety and health may be associated with climate events.

In our analyses, the vulnerable groups in workplaces during hot weather have been identified by gender, age group, business size and industry. The results indicate significant increases in injury claims for male workers with an increase in maximum temperature. Although previous studies have shown women to be less heat tolerant than men (Mathee et al., 2010), male workers should also be target in preventive measurements because males are more likely than females to work in high-risk occupations. Age-specific analysis showed that the greater risk for the middle-aged workers (aged 35–44 years) may be due to the fact that they are more intolerant to work-related heat than young individuals and often take more strenuous work than older people.

The analysis of business size showed that workers in small- and medium-sized enterprises were more vulnerable to work-related injuries with increasing maximum temperature, which is consistent with findings of previous research (Lundgren et al., 2013; Xiang et al., 2014c). In China, small- and medium-sized enterprises commonly lack effective cooling and ventilation systems. In terms of industrial sectors, we showed that the sector with greatest increased risk of work-related injury in association with temperature was manufacturing. These findings suggest that outdoor heat may add to the indoor temperature burden, which also results from heat-generating industrial processes, intense physical work and lack of cooling systems. Given our choice of the level of statistical significance, we could not find significant results for outdoor industrial sectors. This could be possibly due to the small number of injury claims for outdoor workers (less than 200). It was also

possibly affected by high temperature labor protection policies in Guangzhou (The People's Government of Guangdong Province, 2011) which advise the cessation of some outdoor work when the daily maximum temperature is above 39 °C.

In terms of labor protection, China is particularly interesting. To cope with intensive occupational heat exposure, China has released a new regulation: Administrative Measures on Heatstroke Prevention (AMHP2012) (The State Administration of Work Safety et al., 2012; Zhao et al., 2016). The governmental regulation specifies the maximum temperature in the workplace and requires that employers pay high-temperature subsidies to workers in extremely hot environments. For example, according to the regulation in Guangzhou, employers are required to pay a subsidy to workers when the daily maximum temperature exceeds 35 °C. These measures could improve heat protection for workers, though research is still needed to evaluate to their effectiveness (Zhao et al., 2016). The case in China is representative of many developing countries, which hold a dense population, experience severe and frequent heat exposure, and face rapid urbanization but have less capacity to adapt to climate change. Our study may arouse more attention on the heath of people working under risky hot environments both indoors and outdoors.

There are several limitations to this study. The study uses temperature as an indicator of heat stress, without considering the influence of other factors that could play an important role. The most widely used heat stress index in occupational studies is the Wet Bulb Globe Temperature (WBGT) that considers air temperature, humidity, solar radiation and wind speed in a single index. The use of this index would have been preferable in our assessment as it would provide a more valid measure of total heat stress (Gao et al., 2017). However, this index is not routinely measured and we did not have the necessary data to estimate it. Secondly, we did not have information on the detailed conditions of the occurrence of injuries, such as the location (indoor or outdoor, the prevalence of air conditioning). This would have allowed for improved inferences on the potential impact of outdoor temperatures on indoor injuries. Thirdly, the Work Injury Insurance system is not universal and the majority of migrant workers are not included in the system. Immigrants are widely distributed in the manufacturing, construction and other low-end labor markets, which may result in under-ascertainment of relevant injuries. Finally, the use of the case-crossover design, in which workers were matched to themselves, eliminated the potential for time-invariant confounding at the individual level, including confounding by socioeconomic status and time-invariant behavior patterns, which is often a primary concern in work-related injury.

In conclusion, our results suggest that the risk of work-related injuries is significantly associated with hot weather in Guangzhou, China. In the context of climate change, increases in global temperatures and in frequency of warm nights are expected, and the results of this study could be helpful to estimate future impacts of global warming on workers, as well as to develop climate adaptation strategies.

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Conflicts of interest

None.

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